Steve Blanc
Phil Haves
Rich Hackner
Holmberg

Unique Tracking Number Assigned by MORTS __________________

RESEARCH TOPIC ACCEPTANCE REQUEST (RTAR) FORM

TC/TG: TC 7.5 – SMART BUILDING SYSTEMS

Title: A Building Systems Emulation Tool for Building Operators

Applicability to ASHRAE Research Strategic Plan:
I ENERGY and RESOURCES -- Develop evaluation methods that allow reductions in energy, cost, and emission and improvements in comfort, health, and productivity to be quantitatively measured.
II INDOOR ENVIRONMENTAL QUALITY -- Develop self-diagnostic inspection methods for HVAC systems that minimize negative impacts on comfort, health, and productivity.
Research Classification: Advanced Concepts -- High Risk, Innovative and Emerging Technology
TC/TG Priority: (1, 2, or 3)
TC Vote: (For –Against-Abstentions-Absent-Total) XX/XX/XX/XX
(Abstentions) XX (Negative Votes) XX
Reasons for Negative Votes and Abstentions:

Estimated Cost: $100,000 Estimated Duration: 24 months
Other Interested TC/TGs:
Not Reviewed yet: 4.7 Energy Calculations; 7.4 Building Operations Dynamics)

Possible Co-funding Organizations: TBD

Application of Results:
Applications Chapter 37 Testing, Adjusting and Balancing
Applications Chapter 38 Operation and Maintenance Management
Applications Chapter 39 Computer Applications
Applications Chapter 40 Building Energy Monitoring
Applications Chapter 41 Supervisory Control Strategies and Optimization.

State-of-the-Art (Background):
(Brambley and Haves, 2005) provides an overview of many issues, discussing emulation for training, FDD (Fault Detection and Diagnosis) and operational strategizing and optimal control. NIST developed "emulators" in the mid 1980's for "hardware-in-the-loop" control systems testing IEA (International Energy Agency) Annex 17,(Building Energy Management Systems - Evaluation and Emulation Techniques) used international teams developing emulators for "evaluating building energy management system methodology (Annex 17 Website). (Kelly and May, 1990) used "an emulator / tester consisting of a computer-based simulation of a building and its mechanical system connected to the BEMS [Building Energy Management System] in place of its sensors and actuator". (Liebecq, Nusgens and Wang, 1991), (Vaezi-Nejad, Hutter, et al, 1991), (Kaerki and Lappalainen; 1994) also designed prototype emulators to test such aspects as accuracy, time-step, zone temperature control changes and tuning loop parameters. Annex 17 showed emulation to be feasible, but its products were "one-off" research tools limited by the fact that that only the thermal processes were treated explicitly, fluid flow simulation was idealized. Fan systems could not be accurately modeled (Haves, Norford, and DeSimone, 1998).
(Kelly, Kao, Park, May; 1994) describe the I/O to emulator connection and test condition selection and issues raised by transitioning between types of weather test days. A "low cost" emulator is developed (Decious, Park, Kelly, 1997) by changing simulation applications and placing the emulator system on one computer, using it to investigate effects of tuning strategies on actuator life. (Ahmed, Mitchell and Klein, 1998) utilized both mass and energy flows to get temperature and pressure differentials in a simulation of a lab, results compared well to actual results gathered with EMS sensors.
(Haves, Norford, and DeSimone, 1998) ASHRAE 825-RP to developed a simulation test bed for control algorithms and strategies and pursued component models in the simulation, multi-tasking processes on the same computer as the plant simulation, and used standard protocols to tie the system to controls hardware. (Mahdavi, 1998) showed that the model could be run backward in time (to analyze the building's past behavior and /or to calibrate the model) while running the model forward would predict the building's response. Running an emulator bi-directionally can facilitate training of operators.

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(Haves, Salisbury, Claridge and Liu 2001) created information requirements for model to predict the performance of an actual building, focusing on sources of input error and simulation deficiencies. They focus on calibrated simulations and communication need for passive monitoring and active testing.
(Haves, Xu, Deringer, 2004) used a low-cost hardware interface using plug-in A/D and D/A cards in a PC linking a simulated building and HVAC system with a real building control system.
As can be seen from these citations, most of the issues involved in emulator design have been dealt with, the major question is now ,can a generic system be built for building operators to use?
(Henze, Plamp and Strassberger 2005) and (Henze and Plamp, 2005) designed the BASmobile to be mobile and small scale building automation systems laboratory for teaching and research. The lab combines simulation and physical emulation of central plant and distribution systems. There is clearly a need not only for training and educational systems are the general level but for the individual in the field dealing with a particular system in a an individual building.

Advancement to the State-of-the-Art:

This research would develop a tool that would be extremely valuable to building operators. In the larger buildings, 20-30% of the commercial marketplace using this tool, large office buildings, retail, institutional and light industrial, and savings would be easily 10% of current energy usage or better depending on how the tool was used.

Justification and Value to ASHRAE:

This tool would have a direct impact on the training and operations of building operators in commercial and light industrial sectors. Should the system prove to be practical, the potential marketplace would encompass some 30% of the facilities in those sectors, realistically it would take 10 to 15 years to affect about 56-60% of these market sectors. The questions are, can it be built and will industry adopt it? The chances are 30-50%. Should ASHRAE fund this development and market it to control companies, there is a good chance it could use the intellectual property rights of those emulator parts developed in the project for the society.

Objective:

Ultimately, the creation of a tool that will provide emulation of a specific building and its systems or a generic model for training of operations personnel and exploration of building problems or potential operational alternatives.
A Building Systems emulation tool would provide building operators valuable support for a number of functions supporting building operations. This system, linked to the building controls for input and emulation purposes would support:

- Training of building operators either generally, or on a specific building
- Control Strategizing / Optimal Control(including Demand Response strategies)for occupant comfort and/or operating cost as well as benchmark building performance/develop a history of performance
- Fault Detection and Diagnostics (broad gauge, whole building and major systems levels)
    - Identify critical control points that may justify more O&M as far as calibration checks, etc.
    - Resetting alarm ranges or Identifying building-specific relational checks
- Running "What if" scenarios on a number of operational and equipment variables such as:

Assess how the building will react to changing start-up and shutdown sequences
Assess value of upgrading equipment and/or performing periodic maintenance
Assess the value of using nighttime purges, different load shed options, cooling tower free cooling, raising/lowering set points, chiller/fan/pump sequencing, etc.
This research would investigate the parameters of different combinations of simulation / emulation approaches seeking the balance of "Generic simulation" vs. specific / special modeling on specific components and systems and the relationship between the building, its model and the control systems. Researchers will have to develop a feasible design responding to the constraints of cost, speed and fidelity to actual building dynamics. The research process would encompass a review of previous work both in the building systems and related emulation / simulation fields, such as chemical and industrial process engineering, manufacturing, computer science, economics, etc. The researchers would then develop a functional specification for a proposed emulator system and its information requirements.(e.g., architecture, functionalities, communications protocols); and determine feasibility both the <u>technical and economic</u> feasibility of such a tool. What platform(s) are available to use that will give us reasonable accuracy with tradeoffs for minimum input requirements? What type of a front-end would be required for the operator-building interface? How can we minimize the type and number of inputs required and still be able to emulate building specific characteristics? What precision can be expected? What type and

amount of historical data would be required to properly calibrate the tool? Can we capture a snap shot of the building to use as the starting point of the simulation for what ever purpose? What level of effort would be required to build and test the tool in a follow-on project?

This phase would prove feasibility, focusing on evaluating proposed concepts for some simple building applications as a "proof of concept". Subsequent phases would build on this design to produce a prototype emulator by expanding the database of component and systems.

Key References:

Ahmed, O., Mitchell, J.W., Klein, S.A..; Experimental validation of thermal and pressure models in a laboratory simulator; ASHRAE transactions 1998: Vol 104, Part 2, , 20 Jun 1998 pp 983 - 998

Brambley, M.R., Haves P., McDonald, S.C., Torcellini, P., Hansen, D., Holmberg D.R., Roth, K.W.; Advanced Sensors and Controls for Building Applications: Market Assessment and Potential R&D Pathways; April 2005, US DoE Contract DE-ACO5-76RL0 1830 PNNL, Richland, Washington

Decious, G. M.; Park, C.; Kelly, G.E.; Low-Cost Building/HVAC Emulator; Heating/Piping/Air Conditioning (HPAC), v69 n1, p188-193, Jan 97.

Haves, P., Norford, L.K., and DeSimone, M.; A Standard Simulation Testbed for the Evaluation of Control Algorithms & Strategies, *ASHRAE Trans*, 104, Pt 1, 1998, Paper 4140 RP-825

Haves, P., Peng Xu, Deringer,J, A Simulation-Based Testing and Training Environment for Building Controls; SimBuild 2004; August 2004

Haves, P., Salsbury, T., Claridge, D., Liu, M; Use of whole building simulation in on-line performance assessment: Modeling and implementation issues; 7th Int'l IBPSA Conference Building Simulation; Rio de Janeiro, Brazil August 13-15, 2001

Henze, G.P., Plamp, S., Strassberger, G.; A Mobile Laboratory for Building automation and Control Systems – Part 1: Laboratory Development**;** ASHRAE Transactions Denver 2005, Paper 4785.

Henze, G.P., Plamp, S.; A Mobile Laboratory for Building automation and Control Systems – Part 2: Application in Education; ASHRAE Transactions Denver 2005, Paper 4793.

IEA Annex 17 BEMS Evaluation and Emulation Techniques
http://www.ecbcs.org/annexes/annex17.htm

Kaerki, S.H., Lappalainen, V.E.; A new emulator and a method for using it to evaluate BEMS; ASHRAE Transactions: Volume 100, Part 1; 22-26 Jan 1994 ; p 1494-1505

Kelly, G.E.; Kao, J.Y.; Park, C., May, W.B.; Using emulators to evaluate the performance of building energy management systems; ASHRAE transactions: Volume 100, Part 1; 1994 Winter Mtg.; 22-26 Jan 1994; p 1482-1493

Kelly, G.E., May, W.B. Jr.; The concept of an emulator /tester for building energy management system performance evaluation;; ASHRAE Transactions 1990 Winter Meeting; 11-14 Feb 1990, pp. 1117-1126

Liebecq, G.A.; Nusgens, P.J.; Wang, S.; Technical aspects of the design of an emulator for building energy management systems; ASHRAE Transactions 1991 Winter meeting; New York, NY; 19-23 Jan.

Mahdavi, Ardeshir; Toward a Simulation–Assisted Dynamic Building Control Strategy; Carnegie Mellon Univ., Pittsburgh, PA

Vaezi-Nejad, H., Hutter, E., Haves, P.; Dexter, A. L.; Kelly, G.; Use of Building Emulators to Evaluate the Performance of Building Energy Management Systems; Proceedings of Building Simulation Conf., Nice, France, August 20-22, 1991, p209-213; IBPSA The International Building Performance Simulation Assoc.

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Rich Hackner
Holmberg

Details:

as noted in the examples following:

1. Generic building + real controls: training, controls product testing
2. Generic building + simulated controls: control algorithm/strategy development (inc. diagnostics)
3. Specific building + real controls - not connected to real building sensors/controls, training, short-term what-if
4. Specific building + real controls - connected to real building sensors/controls: immediate what-if, diagnostics
5. Specific building + simulated controls - not connected to real building sensors/controls: training, longer-term what-if, control strategy development

Brandemuehl
Katipalmula